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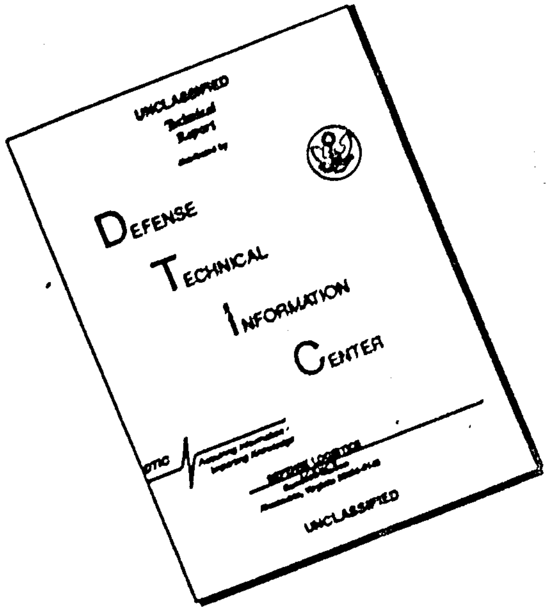

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

LENGTH CHANGE OF CONCRETE CONTAINING GLEN CANYON DAM AGGREGATE AND VARIOUS CEMENTS, POZZOLANS AND/OR A LIGNIN-TYPE RETARDING AGENT

CONCRETE AND STRUCTURAL BRANCH

Laboratory Report No. C-1068

DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

November 11, 1963

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Laboratory Report No. C-1068
Compiled by: J. R. Graham
Checked by: E. M. Harboe
G. G. Hoagland
Reviewed by: J. E. Backstrom
Submitted by: E. C. Higginson

Subject: Length change of concrete containing Glen Canyon Dam aggregate and various cements, pozzolans and/or a lignin-type retarding agent.

INTRODUCTION

Glen Canyon Dam, located on the Colorado River in northern Arizona, is a gravity-arch dam containing 5 million cubic yards of concrete. As in nearly all recently constructed Bureau of Reclamation massive concrete dams, the concrete in the dam proper contains a pozzolanic material as a replacement for a portion of the cement. The two principal reasons for using pozzolan are (1) economy, and (2) the reduction of heat generation during hydration accruing to its use. Further economies and advantages in the form of reduced cementitious material content, and the attendant reduction in heat generation, usually accompany the use of water-reducing, set-retarding agents.

A preliminary pozzolan investigation, reported in Concrete Laboratory Report No. C-882, evaluated, for compliance with requirements of Specifications No. DS-5053, pozzolans from 74 sources. Selected pozzolans from these sources that met all specifications requirements together with 12 additional pozzolans from different sources, Table 1, were subjected to tests in concrete. Preliminary laboratory concrete investigation, partially reported in Concrete Laboratory Report No. C-526A, was undertaken to evaluate the individual and/or combined effects of various pozzolans and a single lignin base retarding agent on selected properties, such as compressive strength, elastic properties, and length change, including autogeneous and drying shrinkage and expansion due to prolonged moist curing of Glen Canyon Dam concrete. Reported herein are the results of this investigation.

CONCLUSIONS

From results of tests reported herein, the following conclusions appear to be justified:

1. The use of any of the pozzolans tested; namely, fly ash, clay, shale, pumice, volcanic ash, and blast furnace slag (1) increased, except for fly ash, the water requirement, (2) slightly increased

autogeneous shrinkage, (3) significantly increased drying shrinkage, and (4) decreased the compressive strength (modified cubes) and elastic properties as compared to similar values obtained from control concretes, Tables 2-4, Figures 2-5.

2. Addition of calcium lignosulfonate retarding agent to concrete mixes reduced the water requirement about 10 percent while maintaining the same workability, and generally resulted in somewhat increased drying shrinkage, Table 5, Figures 6, 7, and 8.

3. Expansion of continuously fog-cured concrete containing pozzolan in the amount of 30 percent by weight of cementitious material exceeds the average expansion of control concrete containing no pozzolan by 33 to 120 percent, Figure 1.

TEST MATERIALS, APPARATUS, AND PROCEDURES

Materials

Aggregate for the laboratory concrete mixes was obtained from the Wahweap deposit which is located about 7 miles northwest of Glen Canyon Dam. The pit run material was shipped to the Denver laboratories, after which it was washed and screened through the laboratory aggregate-processing plant. After drying, the sand was separated into six sizes, Sieves No. 8, 16, 30, 50, 100, and pan, through jigger screens. Lightweight material was removed from the No. 8 size sand and coarse aggregate by the heavy media separation process. Physical properties were then obtained for use in concrete mix design, prior to storing for subsequent use in concrete mixes.

Concrete mixes contained five different Type II, low-alkali cements as follows: Laboratory Samples No.; M-2400, an equal blend of cements obtained from 10 different sources; M-3196, from California; M-3100, an equal blend of cements obtained from 10 different sources; M-3329, from California; and M-3688, from Arizona. Concrete mixes contained 22 different laboratory samples of pozzolans consisting of the following types: clay, shale, pumice, fly ash, and volcanic ash. Pozzolan samples were obtained from various locations throughout the middle and far west states, except for a few which were obtained from the same source, but ground to different finenesses, or calcined under different conditions.

Calcium lignosulfonate water-reducing, set-retarding agent, in the amount of 0.37 percent by weight of cementitious material, was used in seven of the concrete mixes, namely Nos. 99, 103, 112, 116, 123, 134, and 161.

Neutralized vinsol resin (NVX) was the air entraining agent used.

Apparatus

Equipment used in the fabrication of the 4- by 4- by 30-inch test specimens consisted of steel molds, Figure 9, and a vibrating table on which the molds were placed for consolidation of the fresh concrete, Figure 10. Length change of the specimens was measured on a horizontal comparator, Figure 11. Data for determining Young's dynamic modulus of elasticity were obtained from an electronic system consisting of an audio oscillator, a driver and pickup, and an amplifier-oscilloscope indicator, Figure 12. Flexural modulus of elasticity and modulus of rupture data were obtained by use of a loading frame and dial gages, shown in the 120,000-pound Universal testing machine, Figure 13.

Procedures

Four- by four- by thirty-inch specimens for the first series (Mixes No. P-1 through P-21) were fabricated from mixes initially designed to contain 1-1/2-inch-maximum-size aggregate; whereas, specimens of the same size for the second series (Mixes No. 31 through 161) were fabricated from a mass concrete mix that was wet-screened to contain 1-1/2-inch-maximum-size aggregate. Drying shrinkage specimens (Nos. 5 and 6) were cured at 100 percent relative humidity and 73.4° F for 14 days and then at 50 percent relative humidity and 73.4° F until 1 year's age. Autogenous cured specimens (Nos. 19 and 20) were hermetically sealed in copper jackets immediately after fabrication and stored at 73.4° F for the duration of tests. Specimens No. 1 and 2 were continuously cured at 100 percent relative humidity and 73.4° F. All specimens were measured for length change and Young's modulus of elasticity periodically.

Each of the specimens, after 1 year of curing under their individual curing conditions, was tested in flexure. Specimens, when tested in the flexure frame, were rotated one-quarter turn from the position in which they were fabricated. Autogenous cured specimens and those with rough surfaces were sulfur capped at the bearing points, Figure 13. Compressive strengths of modified cubes were determined after the flexure tests.

DISCUSSION

This investigation included 18 relatively rich preliminary concrete mixes containing 30 percent pozzolan (five types) by weight of cementitious material, Tables 1, 2, and 3. Also included were 21 comparatively lean concrete mixes containing 33 percent

pozzolan (four types) by weight of cementitious material in nine different blends, Table 4. In addition were 13 mixes containing 4 different blends of pumice pozzolan generally in the amount of 33 percent by weight of cementitious material, with 7 of these mixes containing 0.37 percent calcium lignosulfonate-retarding agent by weight of the cementitious material, Table 5. The 13 latter mixes contained 3 different blends of cement. Results of tests performed on the preliminary concrete mixes, Figures 1 and 2, indicated that pozzolans are suitable, with respect to length change, for use in interior mass concrete. The cementitious material in these pozzolan mixes was composed of 30 percent pozzolan (140 to 169 lb/cu yd) and 70 percent cement (315 to 393 lb/cu yd); whereas, the control mixes contained approximately an equivalent weight of cement but no pozzolan, Tables 2 and 3. The second set of mixes, Tables 4 and 5, was prepared with a lower cement content than the "P" series and 33 percent pozzolan to determine the feasibility of using a more economical and workable mix with pozzolans.

From a comparison of the drying shrinkage of specimens fabricated from Mixes No. 111 and 112 with 115 and 116, there are indications of greater drying shrinkage attending the use of a coarser pozzolan.

Results of tests on specimens continuously moist cured (Nos. 1 and 2) indicate that the addition of pozzolans to the mixes will increase the expansion of concrete as compared to the expansion of nonpozzolan concrete similarly cured.

Two sets of sealed bars were fabricated to determine whether or not any free surface moisture remains after 14 days of curing at 73.4° F. The first set (GCD-111, 19, and 20) contained no retarder, while the second set (GCD-112, 19, and 20) contained a calcium lignosulfonate-retarding agent, and both sets of specimens contained pozzolan. There was no free surface moisture apparent on any of the specimens when the copper jackets were removed after 14 days. These bars were then stored at 50 percent relative humidity and 73.4° F to 1 year's age, at which time they had developed a slightly higher shrinkage than companion specimens that had been initially stored for 14 days at 100 percent relative humidity and 73.4° F, Figure 7.

ACKNOWLEDGMENT

Significant contributions were made to this investigation and subsequent report by J. C. Librande, L. R. Carpenter, H. S. Fouts, H. F. Avery, E. L. Ore, and the Mix Design Unit. Appreciation is extended to all who contributed their technical assistance and cooperation.

Table 1

POZZOLANS USED IN LABORATORY CONCRETE MIXES
Length Change Investigation
Glen Canyon Dam

Pozzolan No.	Type
M-2529 1/	Clay
M-2575 1/	Clay
M-2537	Shale
M-2540	Pumice
M-2564	Fly ash
M-2626	Shale
M-2833 3/	Clay
M-2834 3/	Clay
M-2835	Volcanic ash
M-2858	Volcanic ash
M-2883	Pumice
M-2907-C3 2/	Shale
M-2907-C4 3/	Shale
M-2909-A	Volcanic ash
M-2942	Pumice
M-2942-A	Pumice
M-2942-B	Pumice
M-3439-A	Pumice
M-3439-B	Pumice
M-3470-B	Pumice
M-3587	Pumice
M-3837	Pumice

1/ Calcined by producer.
2/ Calcined for 3 hours at 1,600° F.
3/ Calcined for 4 hours at 1,600° F.

Pozzolans M-2529 through M-2626 were used in P-1 through P-21 mix series.

A and B denotes the fineness of the pozzolan, A being the coarser of the two.

Table 2

DRYING-SHRINKAGE LENGTH CHANGE, COMPRESSIVE STRENGTH, AND ELASTIC PROPERTIES OF PRELIMINARY CONCRETE MIXES CONTAINING POZZOLAN
Length Change Investigation--Glen Canyon Dam

Concrete Mix Data										Length Change Data[1]													
Mix No.	W/(C+P)	Water lb/yd³	Cement[4] lb/yd³	Pozzolan % [2]	Pozzolan lb/yd³	Pozzolan No.	Pozzolan Type	Air %	Slump, in.	Bar No.[3]	Drying shrinkage: Length change in millionths, Days of drying 14	28	90	120	180	270	365	Compressive strength of modified cubes, psi	Modulus of rupture, psi	Flexural E, million psi	Dynamic E, million psi, Age 7	28	379
P-1	0.53	252	474	0	0		(Control)	4.0	3.0	P-1 (5-6)	225	305	462	492	512	520	522	6,040	760	4.4	4.4	5.0	5.0
P-1R	0.53	251	471	0	0		(Control)	4.2	3.3	P-1R (5-6)	255	332	486	520	550	565	568	6,060	740	4.2	4.4	4.8	4.9
P-2	0.60	279	326	30	140	M-2529	Clay	4.8	3.4	P-2 (5-6)	330	425	578	617	665	693	702	4.960	575	3.0	3.2	3.7	3.4
P-3	0.60	280	328	30	141	M-2575	Clay	4.7	3.1	P-3 (5-6)	330	425	578	617	665	693	702	4,870	610	3.0	3.2	3.8	3.5
P-4	0.60	283	331	30	143	M-2537	Shale	4.1	3.5	P-4 (5-6)	370	482	652	682	707	723	730	5,020	600	3.2	3.3	4.0	3.6
P-5	0.55	261	329	30	142	M-2540	Pumice	4.2	3.4	P-5 (5-6)	370	482	652	682	707	723	730	5,070	560	3.2	3.5	4.1	3.6
P-6	0.51	239	327	30	141	M-2564	Fly ash	4.9	3.3	P-6 (5-6)	255	332	486	520	550	565	568	5,670	660	4.0	3.9	4.3	4.5
P-7	0.55	260	469				Blast furnace slag	4.5	3.5	P-7 (5-6)	370	482	652	682	707	723	730	5,280	620	3.5	3.7	4.2	4.1
P-8	0.56	265	328	30	141	M-2626	Shale	4.3	3.1	P-8 (5-6)	330	425	578	617	665	693	702	5,470	585	3.3	3.6	4.1	3.8
P-9	0.53	250	472	0	0		(Control)	4.2	3.4	P-9 (5-6)	255	332	486	520	550	565	568	5,630	770	4.0	4.2	4.6	4.7
P-11	0.53	298	393	30	169	M-2529	Clay	4.4	2.8	P-11 (5-6)	330	425	578	617	665	693	702	6,000	600	3.0	3.5	3.9	3.6
P-13	0.53	279	368	30	158	M-2537	Shale	4.6	2.7	P-13 (5-6)	370	482	652	682	707	723	730	5,150	580	3.2	3.3	3.9	3.7
P-14	0.53	248	469	0	0		(Control)	4.9	3.2	P-14 (5-6)	255	332	486	520	550	565	568	5,630	755	4.1	4.4	4.9	4.9
P-16	0.53	257	340	30	146	M-2540	Pumice	4.5	2.8	P-16 (5-6)	400	516	690	721	756	775	785	5,060	580	2.9	3.5	4.0	3.6
P-18	0.53	238	315	30	135	M-2564	Fly ash	4.2	3.2	P-18 (5-6)	255	332	486	520	550	565	568	5,810	670	3.8	4.2	4.6	4.6
P-19	0.53	249	470	0	0		(Control)	4.3	3.3	P-19 (5-6)	255	332	486	520	550	565	568	5,590	670	4.2	4.2	4.6	4.7
P-21	0.53	270	357	30	153	M-2626	Shale	4.8	2.8	P-21 (5-6)	330	425	578	617	665	693	702	5,310	615	3.2	3.5	4.0	3.8
P-11R	0.53	293	387	30	166	M-2529	Clay	4.0	3 0	P-11R (5-6)	330	425	578	617	665	693	702	5,820	545	2.8	3.3	3.7	3.6

1/Average of two specimens.
2/Percent by weight of cementitious material.
3/Bars cured 14 days at 100 percent relative humidity and 73.4° F previous to drying at 50 percent relative humidity and 73.4° F.
4/Laboratory Sample No. M-2400, laboratory blend, Type II, low alkali.

Table 3

LENGTH CHANGE, COMPRESSIVE STRENGTH, AND ELASTIC PROPERTIES OF PRELIMINARY CONCRETE MIXES CONTAINING POZZOLAN
Length Change Investigation--Glen Canyon Dam

Concrete Mix Data									Length Change Data1/														
Mix No.	W/(C+P)	Water, lb/yd³	Cement2/, lb/yd³	Pozzolan lb/yd³	Pozzolan No.	Pozzolan Type	Air %	Slump, in.	Bar No. 2/	Length change in millionths, Days of curing: 7	14	28	90	120	180	270	365	Compressive strength of modified cubes, psi	Modulus of rupture, psi	Flexural E: million, psi	Dynamic E million psi, Age: 7	28	365
P-9	0.53	250	472	0		(Control)	4.2	3.4	P-9 (1-2)		+ 3	+ 8	+24	+ 30	+ 37	+ 45	+ 52	6,470	690	4.7	4.1	5.0	5.9
P-11	0.53	298	393	169	M-2529	Clay	4.4	2.8	P-11 (1-2)		+30	+49	+84	+ 93	+109	+117	+122	6,830	650	4.3	4.1	4.6	5.4
P-11R	0.53	293	387	166	M-2529	Clay	4.0	3.0	P-11R (1-2)		+53	+75	+111	+122	+135	+151	+163	6,820	565	4.2	3.3	4.4	5.2
P-13	0.53	279	368	158	M-2537	Shale	4.6	2.7	P-13 (1-2)		+17	+30	+61	+ 68	+ 81	+ 90	+ 98	6,430	720	4.6	3.3	4.5	5.5
P-14	0.53	248	469	0		(Control)	4.9	3.2	P-14 (1-2)		+15	+27	+55	+ 62	+ 69	+ 79	+ 84	6,460	700	4.8	4.3	5.1	6.1
P-16	0.53	257	340	146	M-2540	Pumice	4.5	2.8	P-16 (1-2)		+30	+49	+92	+103	+118	+133	+142	7,210	730	4.7	3.6	4.9	5.9
P-18	0.53	238	315	135	M-2564	Fly ash	4.2	3.2	P-18 (1-2)		+17	+30	+63	+ 72	+ 87	+100	+110	7,480	760	5.1	4.2	5.0	6.3
P-19	0.53	249	470	0		(Control	4.3	3.3	P-19 (1-2)		+12	+23	+52	+ 61	+ 73	+ 83	+ 89	6,430	745	5.0	4.0	4.9	6.0
P-21	0.53	270	357	153	M-2626	Shale	4.8	2.8	P-21 (1-2)		+30	+49	+84	+ 93	+109	+123	+132	5,420	720	4.5	3.5	4.5	5.5
P-9	0.53	250	472	0		(Control)	4.2	3.4	P-9 (19-20)	0	- 7	-18	-30	- 29	- 26	- 20	- 14	None	585	4.6	4.0	4.8	5.4
P-11	0.53	298	393	169	M-2529	Clay	4.4	2.8	P-11 (19-20)	0	-16	-40	-95	-120	-135	-138	-138	None	565	4.1	[illegible]	4.4	4.8
P-13	0.53	279	368	158	M-2537	Shale	4.6	2.7	P-13 (19-20)	+ 2	- 8	-29	-80	- 94	-115	-129	-130	None	550	4.1	3.3	4.4	4.9
P-14	0.53	248	468	0		(Control)	4.9	3.2	P-14 (19-20)	+ 4	- 4	-10	-10	- 10	- 10	- 10	- 10	None	605	4.7	4.1	4.8	5.5
P-16	0.53	257	340	146	M-2540	Pumice	4.5	2.8	P-16 (19-20)	+ 4	- 3	-16	-62	- 80	-106	-124	-128	None	770	4.6	3.5	4.6	5.3
P-18	0.53	238	315	135	M-2564	Fly ash	4.2	3.2	P-18 (19-20)	- 7	-13	-19	-36	- 40	- 44	- 44	- 44	None	760	5.2	3.9	4.7	5.6
P-19	0.53	249	470	0		(Control)	4.3	3.3	P-19 (19-20)	- 3	- 7	-10	- 5	- 2	+ 2	+ 5	+ 17	None	550	4.7	4.1	4.8	5.5
P-21	0.53	270	357	153	M-2626	Shale	4.8	2.8	P-21 (19-20)	-14	-16	-20	-38	- 46	- 60	- 77	- 82	None	565	4.4	3.4	4.4	4.9
P-11R	0.53	293	387	166	M-2529	Clay	--	--	P-11R (19-20)	0	-11	-32	-81	- 92	-107	-122	-124	None	585	4.3	3.1	4.1	4.6

1/ Average of two specimens.
2/ Bars No. 1 and 2 were cured continuously at 100 percent relative humidity and 73.4° F. Bars No. 19 and 20 were sealed in copper jackets, and stored at 73.4° F.
3/ Laboratory Sample No. M-2400, laboratory blend, Type II, low-alkali.

Table 4

AUTOGENOUS AND DRYING-SHRINKAGE LENGTH CHANGE, COMPRESSIVE STRENGTH, AND ELASTIC PROPERTIES OF MASS CONCRETE
Length Change Investigation
Glen Canyon Dam

Concrete mix data and Drying length change data 1/

Mix 6/ No.	W/(C+P)	Water lb/yd3	Cement 2/ lb/yd3	Pozzolan lb/yd3	Pozzolan No.	Pozzolan Type	Air %	Slump in.	Bar No.	Length change in millionths 5/, days of drying: 7	14	28	90	120	180	270	365	Compressive strength of modified cubes, psi	Modulus of rupture psi	Flexural E million psi	Dynamic E million psi, age: 7	104	379
GCD 31	0.54	152	282	0			5.4	2.5	GCD-31 (5-6)	104	175	250	349	370	395	405	407	5,140	635	4.84	5.2	5.4	5.3
32	0.56	161	190	95	M-2833	Clay	5.0	2.0	GCD-32 (5-6)	110	204	272	394	422	450	460	465	4,240	505	3.88	4.6	4.8	4.7
33	0.58	165	189	95	M-2834	Clay	5.2	2.0	GCD-33 (5-6)	110	204	272	394	422	455	475	482	3,920	470	3.87	4.7	4.6	4.4
34	0.58	162	187	93	M-2835	Volcanic ash	6.0	2.5	GCD-34 (5-6)	125	222	332	470	500	540	562	568	2,960	420	3.35	3.9	3.8	3.6
37	0.54	153	284	0			5.2	1.9	GCD-37 (5-6)	104	160	230	337	357	376	390	400	4,860	650	5.27	5.6	5.8	5.8
38	0.57	161	188	94	M-2858	Volcanic ash	4.8	2.2	GCD-38 (5-6)	130	187	270	364	386	412	437	443	3,990	480	3.96	4.6	4.5	4.3
41	0.54	153	283	0			4.6	2.2	GCD-41 (5-6)	104	160	230	337	357	376	390	400	4,740	605	4.92	4.9	5.6	5.5
42	0.56	158	188	94	M-2883	Pumice	4.9	2.2	GCD-42 (5-6)	100	180	285	430	455	485	500	507	3,190	470	3.96	4.5	4.5	4.4
45	0.54	151	280	0			4.4	2.1	GCD-45 (5-6)	105	166	244	381	405	420	428	435	4,960	620	5.26	5.3	5.6	5.5
46	0.55	157	191	96	M-2907C-3	Shale	3.4	2.7	GCD-46 (5-6)	155	212	292	420	442	468	480	482	5,080	540	4.37	5.0	5.0	4.9
49	0.54	151	281	0			4.5	2.0	GCD-49 (5-6)	105	166	244	381	405	420	428	435	4,800	645	5.08	5.3	5.6	5.7
50	0.63	178	188	94	M-2909A	Volcanic ash	4.5	4.3	GCD-50 (5-6)	107	171	270	498	545	592	627	639	3,090	355	2.60	3.6	3.3	3.2
57	0.54	152	282	0			4.5	1.6	GCD-57 (5-6)	100	162	254	415	430	448	465	470	4,940	625	4.58	--	--	--
58	0.55	156	190	95	M-2907C-4	Shale	3.5	1.5	GCD-58 (5-6)	130	195	275	440	465	490	505	507	4,810	585	4.24	5.0	5.0	5.0
63	0.54	156	287	0			5.0	1.9	GCD-63 (5-6)	100	162	254	415	430	448	465	470	4,990	630	4.62	5.3	5.4	5.3
64	0.59	170	191	95	M-2942A	Pumice	4.7	2.0	GCD-64 (5-6)	132	217	317	482	510	535	553	560	3,520	415	3.28	4.1	4.0	3.8
69	0.64	152	236	0			4.3	2.1	GCD-69 (5-6)	75	120	185	325	350	368	380	385	3,880	530	4.70	5.0	5.3	5.2
70	0.68	162	191	48	M-2834	Clay	4.4	2.0	GCD-70 (5-6)	110	183	262	419	442	470	485	490	3,560	500	3.80	4.2	4.6	4.3
71	0.67	160	190	48	M-2858	Volcanic ash	4.2	1.9	GCD-71 (5-6)	110	175	260	425	452	475	487	493	3,000	450	3.76	4.3	4.5	4.3
72	0.67	157	188	47	M-2907C-4	Shale	5.0	2.0	GCD-72 (5-6)	100	155	250	417	440	465	482	485	3,370	445	4.14	4.5	4.7	4.5
161 3/	0.48	132	186 4/	89	M-3837	Pumice	4.1	1.6	GCD-161 (5-6)	135	221	307	424	453	475	496	503				4.7	4.7	4.4

Autogenous length change data 1/

Mix No.	Bar No.	Length change in millionths, days of curing: 7	14	28	90	120	180	270	365	Compressive strength of modified cubes, psi	Modulus of rupture psi	Flexural E million psi	Dynamic E million psi, age: 7	90	365
31	GCD-31 (19-20)	-3	-8	-12	-20	-22	-25	-27	-29	None	630	6.1	4.8	5.8	6.0
32	GCD-32 (19-20)	2	5	8	7	4	-4	-21	-36	None	565	4.9	3.6	5.2	5.3
33	GCD-33 (19-20)	2	5	8	6	2	-5	-21	-36	None	470	4.9	3.7	5.3	5.4
34	GCD-34 (19-20)	-3	-8	-14	-25	-28	-34	-39	-43	None	490	5.3	3.9	5.7	5.9
37	GCD-37 (19-20)	-7	-18	-19	-10	-10	-15	-21	-25	None	615	5.7	5.4	6.0	6.2
38	GCD-38 (19-20)	-4	-9	-14	-22	-27	-41	-52	-57	None	545	5.4	4.1	5.8	6.0
41	GCD-41 (19-20)	3	7	13	13	11	8	6	5	None	575	5.4	4.9	5.9	6.1
42	GCD-42 (19-20)	21	14	18	8	0	-12	-21	-32	None	615	5.6	4.0	5.8	6.0
45	GCD-45 (19-20)	6	10	11	4	2	-1	-4	-5	None	675	5.6	5.0	6.0	6.1
46	GCD-46 (19-20)	-8	-23	-35	-44	-47	-50	-52	-54	None	595	5.5	4.8	6.1	6.2
49	GCD-49 (19-20)	20	18	12	-2	-5	-8	-9	-9	None	620	5.7	4.8	5.8	6.0
50	GCD-50 (19-20)	23	31	33	12	0	-13	-24	-32	None	430	4.2	3.3	5.0	5.2
57	GCD-57 (19-20)	10	10	3	-13	-18	-23	-28	-28	None	540	5.1	4.9	5.6	5.8
58	GCD-58 (19-20)	10	-13	-25	-25	-27	-31	-33	-33	None	535	5.4	4.8	5.8	6.1
63	GCD-63 (19-20)	-4	-10	-16	-27	-38	-52	-63	-71	None	585	5.4	4.9	5.9	5.9
64	GCD-64 (19-20)	0	0	-1	-23	-38	-52	-63	-71	None	530	4.8	3.5	5.5	5.6
69	GCD-69 (19-20)	7	10	11	-8	-10	-11	-12	-12	None	495	5.0	4.5	5.7	5.8
70	GCD-70 (19-20)	7	10	11	-8	-10	-11	-12	-12	None	550	5.2	3.7	5.5	5.4
71	GCD-71 (19-20)	7	10	11	-8	-11	-11	-12	-12	None	600	5.6	4.0	5.8	5.9
72	GCD-72 (19-20)	6	-1	-8	-19	-20	-21	-24	-25	None	470	5.0	4.2	5.4	5.6
161	GCD-161 (19-20)	-5	-6	-7	-21	-27	-40	-53	-46	7,430	805	6.5	4.8	5.9	6.3

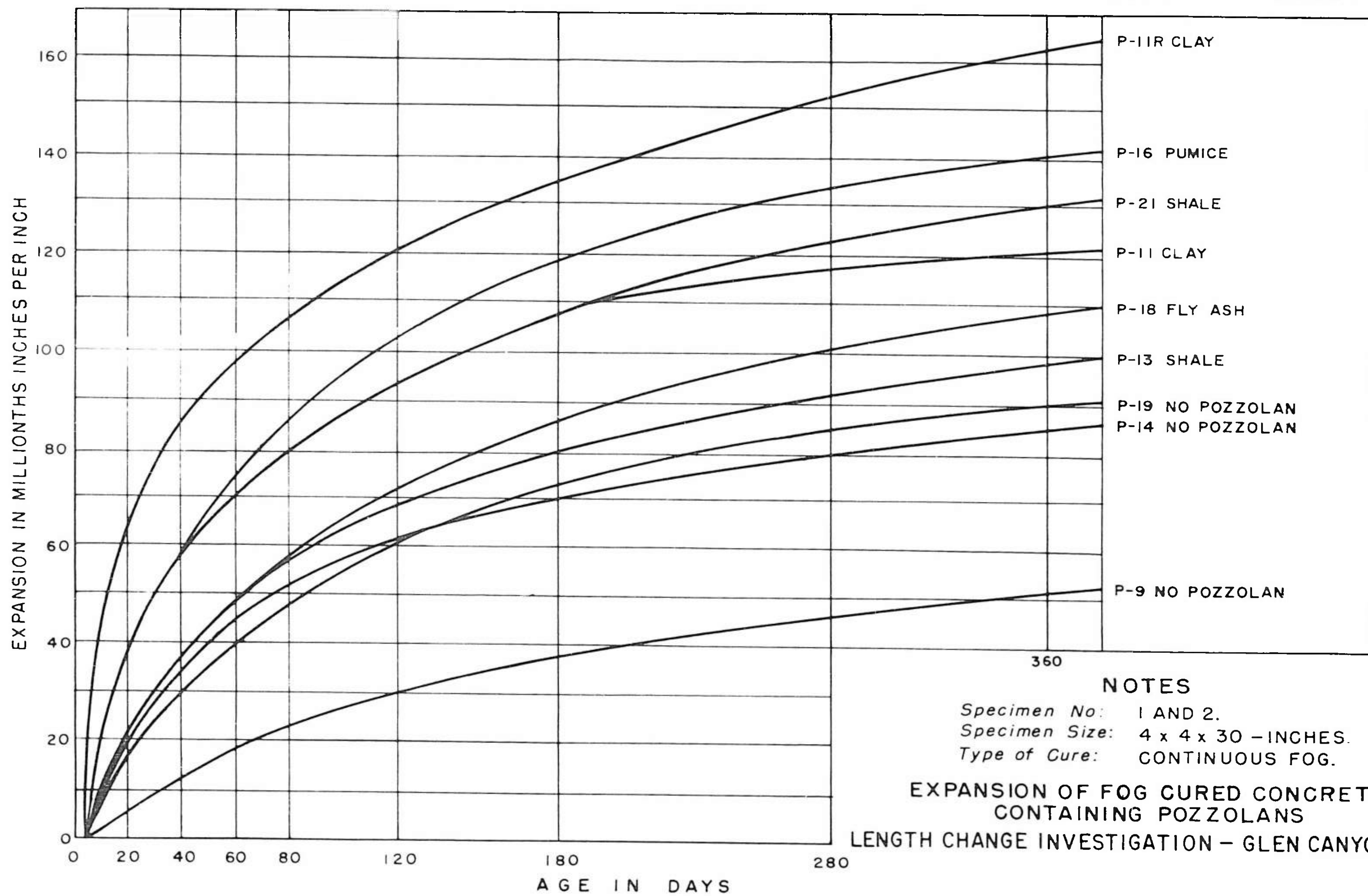
1/Average of two specimens.
2/Laboratory blend, No. M-2400.
3/Contains 0.37 percent calcium lignosulphonate by weight of cementitious material.
4/Laboratory blend, No. M-3688.
5/These values indicate shrinkage and are comparable to the negative values shown under Autogenous length change.
6/Mixes [illegible] to 72 reported in Tables [illegible] and 6 of Laboratory Report C-526-A. Mix 161 unreported to date.

Table 5

LENGTH CHANGE, COMPRESSIVE STRENGTH, AND ELASTIC PROPERTIES OF MASS CONCRETE CONTAINING A RETARDING AGENT
Length Change Investigation--Glen Canyon Dam

Concrete Mix Data											Length change data 1/													
Mix No.	W/C+P	Water, lb/yd3	Cement lb/yd3	Cement No.	Pozzolan 2/ lb/yd3	Pozzolan 2/ No.	Retarding 3/ agent, %	Air %	Slump in.	Bar No.	Length change in millionths 6/, days of drying or curing: 7	14	28	90	120	180	270	365	Compressive strength of modified cubes, psi	Modulus of rupture psi	Flexural E million psi	Dynamic E million psi, Age: 7	104	379
98	0.67	159	190	M-3100	47	M-2942-B	0	4.9	2.4	GCD-98 (5-6)	120	200	322	514	545	573	594	609	3,590	500	3.5	4.0	3.9	3.8
99	0.62	146	189	M-3100	47	M-2942-B	0.37	4.9	3.0	GCD-99 (5-6)	175	280	395	574	610	638	660	674	3,430	475	3.2	4.1	3.9	3.8
102	0.56	159	191	M-3100	95	M-2942-B	0	4.4	2.2	GCD-102 (5-6)	115	172	242	375	396	425	447	450	4,120	515	3.8	4.6	4.6	4.3
103	0.50	143	190	M-3100	95	M-2942-B	0.37	3.7	2.6	GCD-103 (5-6)	158	228	310	454	484	505	528	535	5,410	580	3.7	4.7	4.3	4.4
111	0.56	156	187	M-3329	93	M-3439-A	0	3.9	1.9	GCD-111 (5-6)	150	212	298	442	468	500	525	530	5,520	510	3.7	4.6	4.8	4.3
111	0.56	156	187	M-3329	93	M-3439-A	0	3.9	1.9	GCD-111 (19-20) 4/	180	255	350	458	507	535	555	559	5,320	295	4.1	--	4.8	4.2
112	0.52	139	177	M-3329	88	M-3439-A	0.37	4.2	1.6	GCD-112 (5-6)	145	210	290	398	422	456	475	485	6,080	485	4.2	5.1	5.1	4.5
112	0.52	139	177	M-3329	88	M-3439-A	0.37	4.2	1.6	GCD-112 (19-20) 4/	188	254	337	469	495	525	530	530	5,720	480	4.3	--	4.8	4.3
115	0.55	156	188	M-3329	94	M-3439-B	0	3.5	1.9	GCD-115 (5-6)	145	215	295	400	440	470	490	500	5,420	540	4.0	4.8	4.5	4.2
116	0.53	142	178	M-3329	89	M-3439-B	0.37	5.0	2.0	GCD-116 (5-6)	160	215	280	400	420	450	470	475	5,490	475	4.1	4.9	4.6	4.4
122	0.54	154	189	M-3329	95	M-3470-B	0	5.2	2.3	GCD-122 (5-6)	150	230	337	450	475	506	528	530	4,760	515	3.7	4.4	4.3	4.0
123	0.54	137	170	M-3329	85	M-3470-B	0.37	4.9	2.1	GCD-123 (5-6)	150	230	337	450	475	506	528	530	5,190	530	3.9	4.7	4.4	4.1
133	0.54	157	193	M-3688	96	M-3587	0	3.9	1.7	GCD-133 (5-6)	120	187	266	380	407	434	455	459	4,490	530	4.0	4.4	4.6	4.5
134	0.52	142	181	M-3688	90	M-3587	0.37	3.9	2.7	GCD-134 (5-6)	120	187	266	400	426	451	474	476	4,580	535	4.0	4.5	4.5	4.8
161	0.48	132	186	M-3688	89	M-3837	0.37	4.1	1.6	GCD-161 (5-6)	145	216	304	430	453	475	496	503	4,980	572	3.8	4.7	4.7	4.4
161	0.48	132	186	M-3688	89	M-3837	0.37	4.1	1.6	GCD-161 (1-2) 5/	+ 2	+ 6	+17	+36	+39	+45	+55	+64	7,120	801	5.6	4.7	6.2	6.7

1/ Average of two specimens.
2/ Pumice pozzolan used in all mixes.
3/ 0.37 percent calcium lignosulphonate by weight of cementitious material.
4/ These specimens were sealed in copper jackets, then stripped at 14 days' age and stored at 50 percent relative humidity for drying shrinkage.
5/ These specimens were cured continuously at 100 percent relative humidity and 73.4° F.
6/ Except where length change is indicated +, all changes in length are (-) resulting from drying shrinkage.
7/ Mixes 98-161 unreported to date.



NOTES

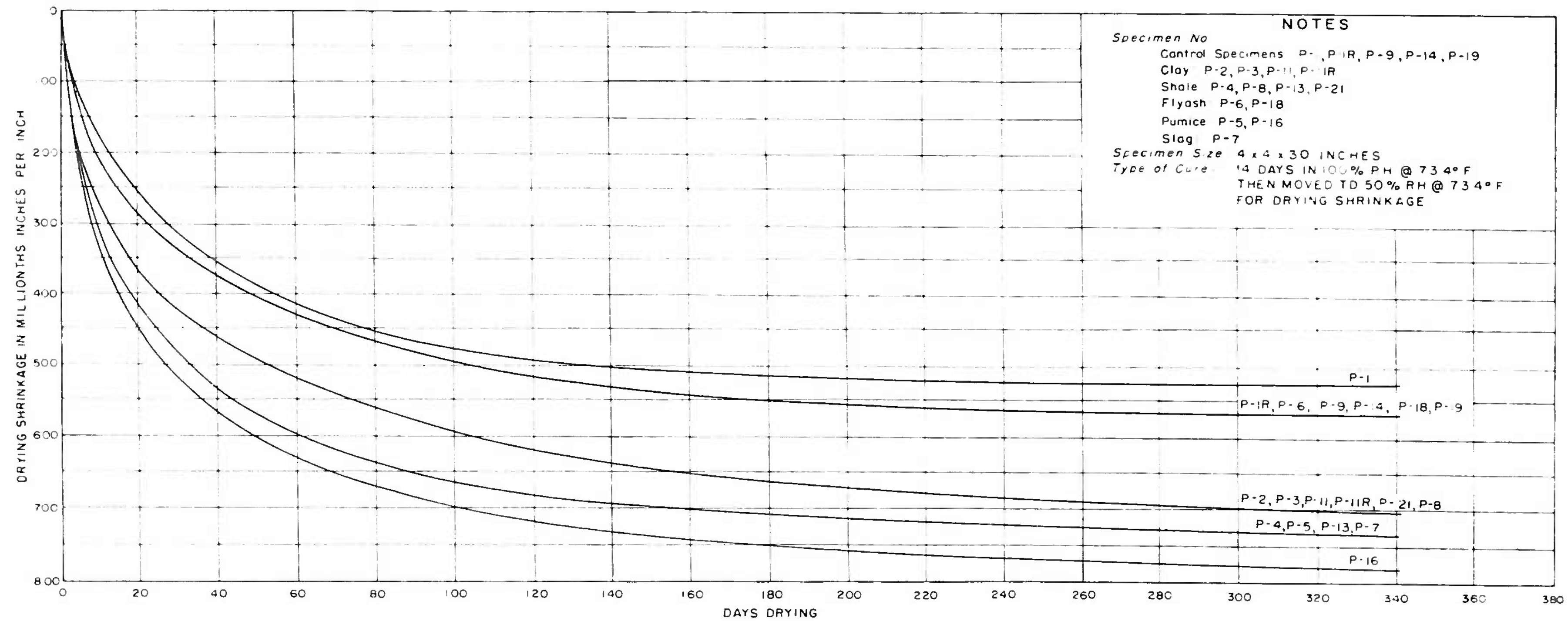
Specimen No: 1 AND 2.
Specimen Size: 4 x 4 x 30 – INCHES.
Type of Cure: CONTINUOUS FOG.

EXPANSION OF FOG CURED CONCRETE CONTAINING POZZOLANS

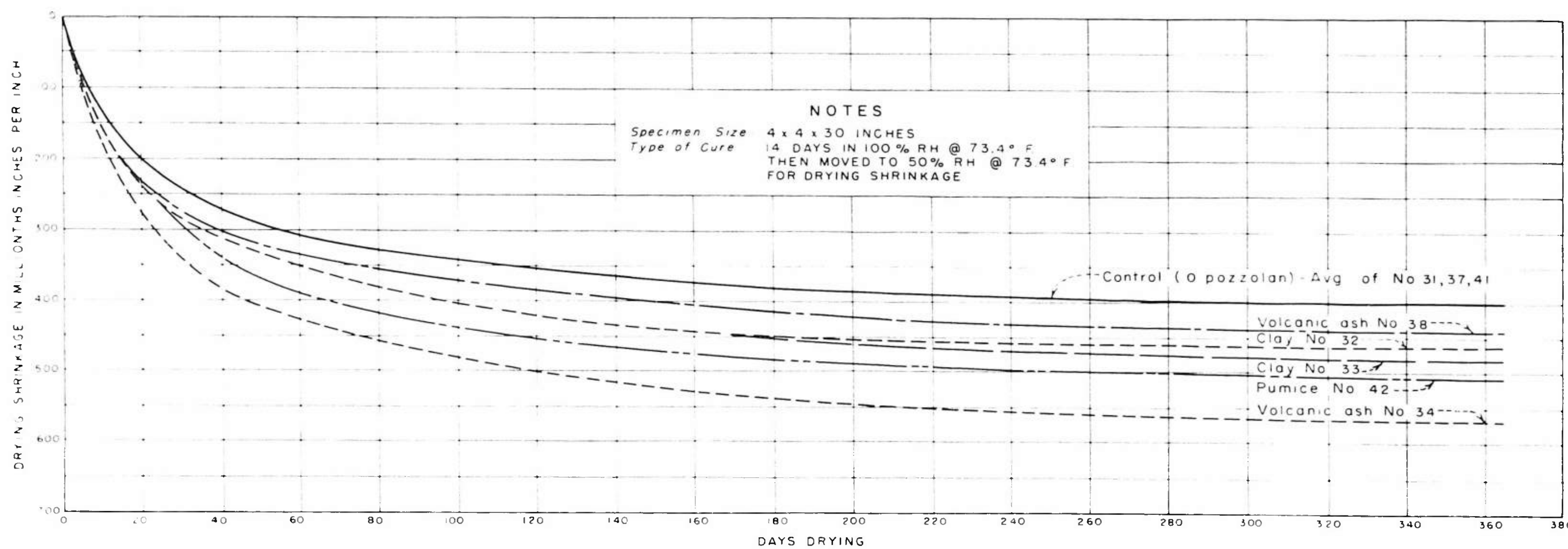
LENGTH CHANGE INVESTIGATION – GLEN CANYON DAM

FIGURE 1

FIGURE 2



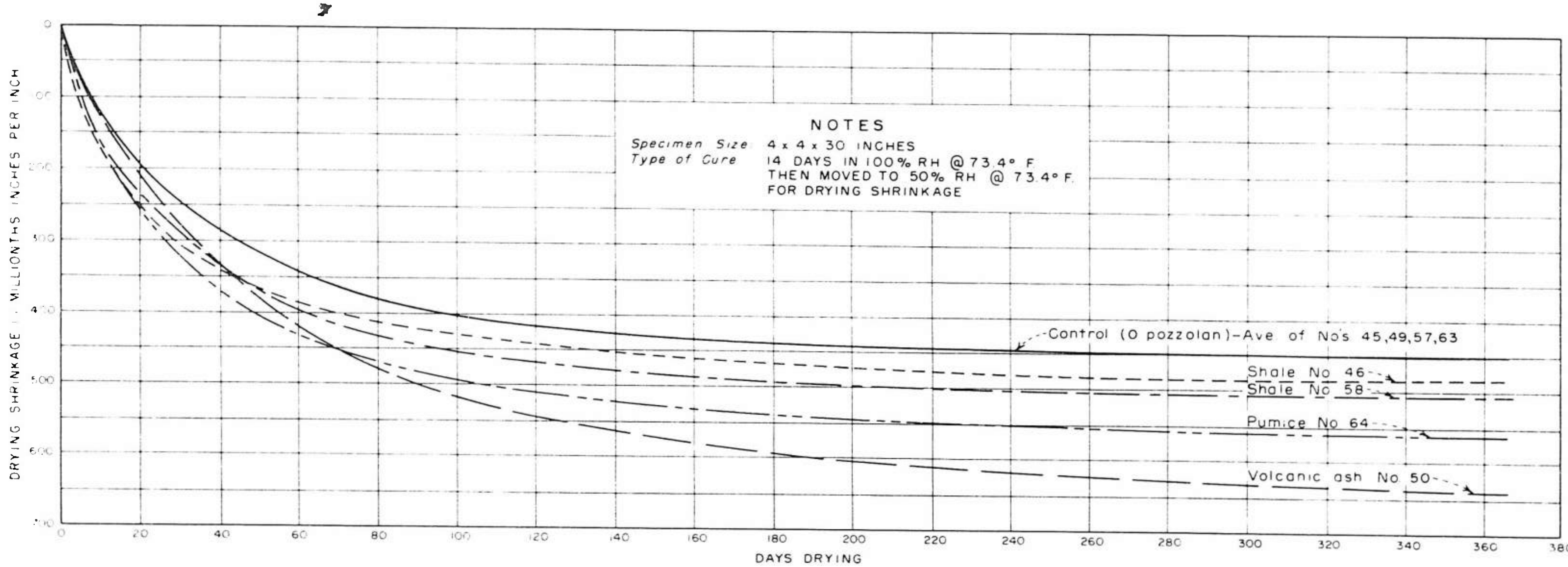
DRYING SHRINKAGE OF CONCRETE CONTAINING POZZOLANS
LENGTH CHANGE INVESTIGATION – GLEN CANYON DAM



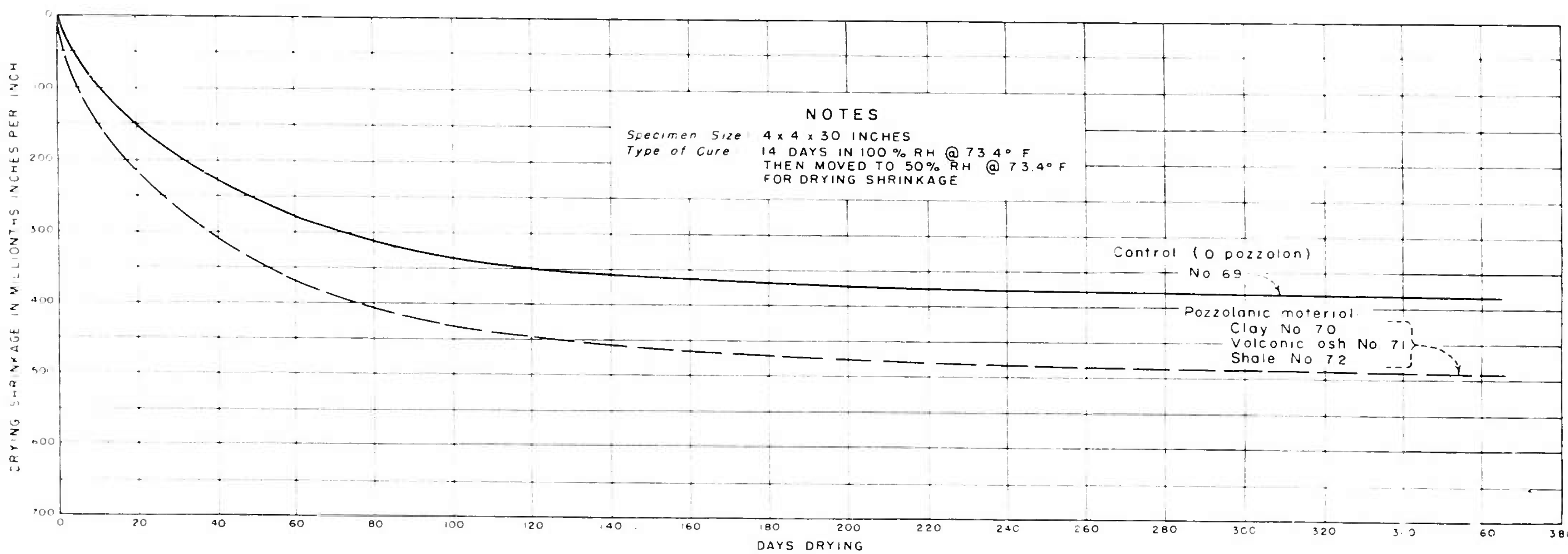
DRYING SHRINKAGE OF MASS CONCRETE CONTAINING VARIOUS TYPES OF POZZOLANS
LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

FIGURE 3

FIGURE 4



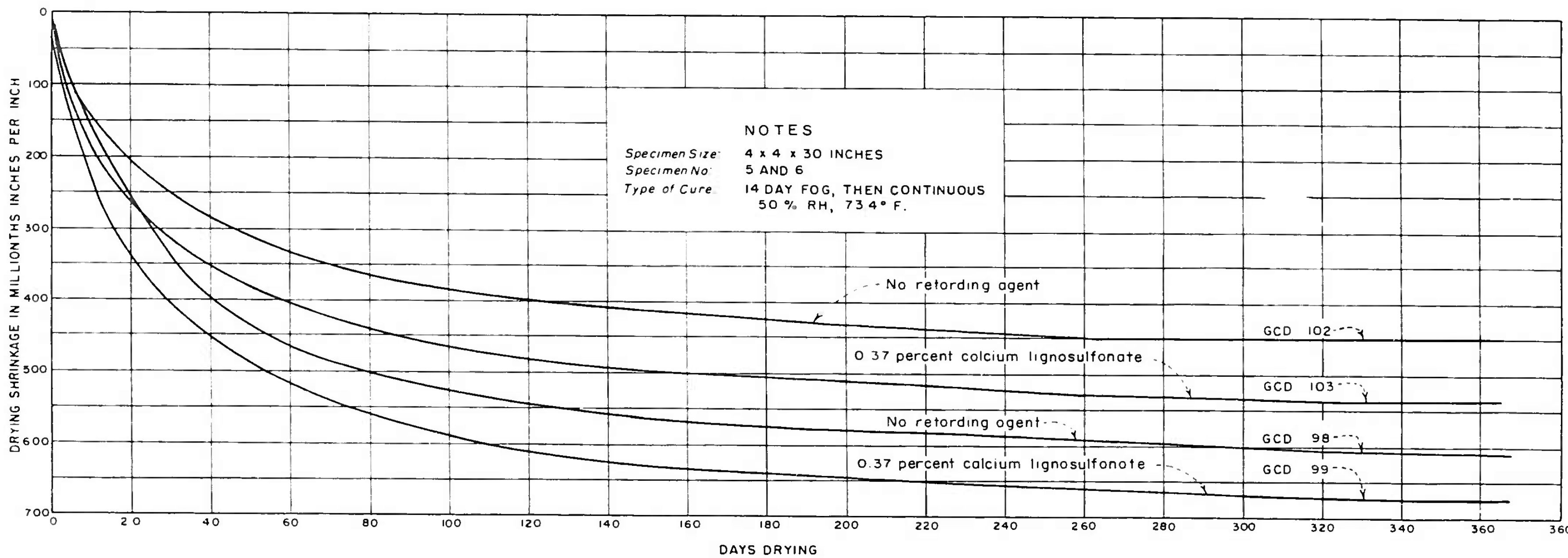
DRYING SHRINKAGE OF MASS CONCRETE CONTAINING VARIOUS TYPES OF POZZOLANS
LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM



DRYING SHRINKAGE OF MASS CONCRETE CONTAINING VARIOUS TYPES OF POZZOLANS
LENGTH CHANGE INVESTIGATION — GLEN CANYON DAM

FIGURE 5

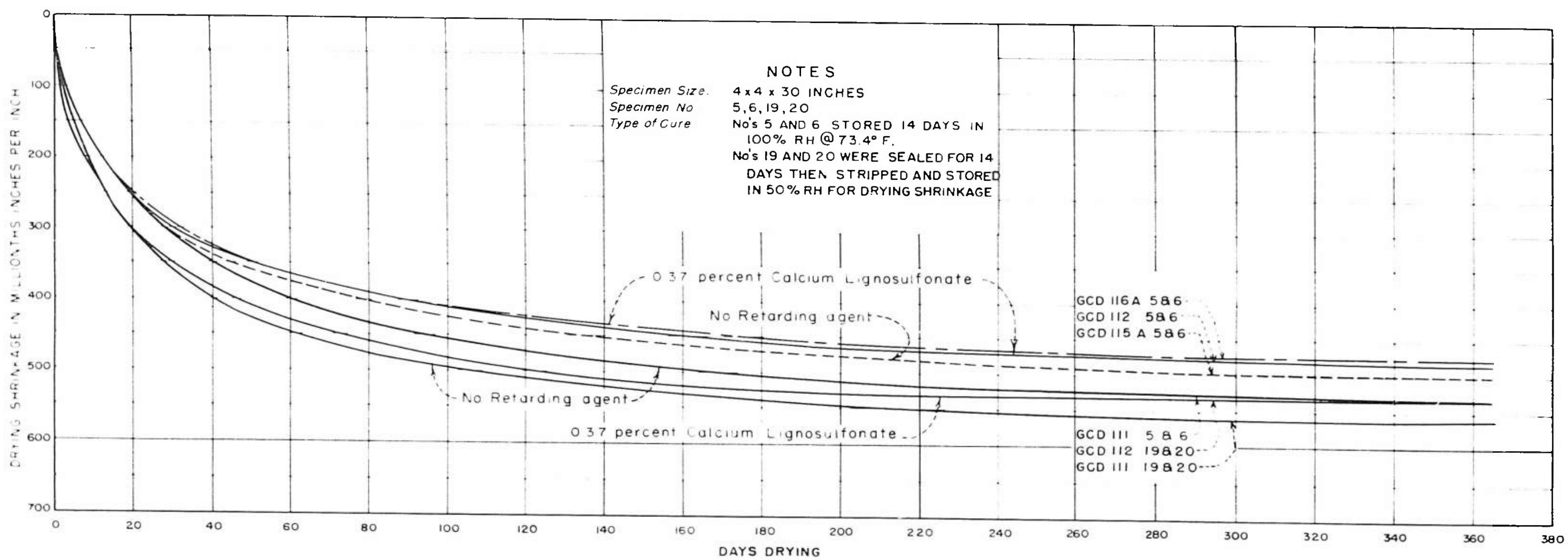
FIGURE 6



DRYING SHRINKAGE OF MASS CONCRETE CONTAINING A RETARDING AGENT

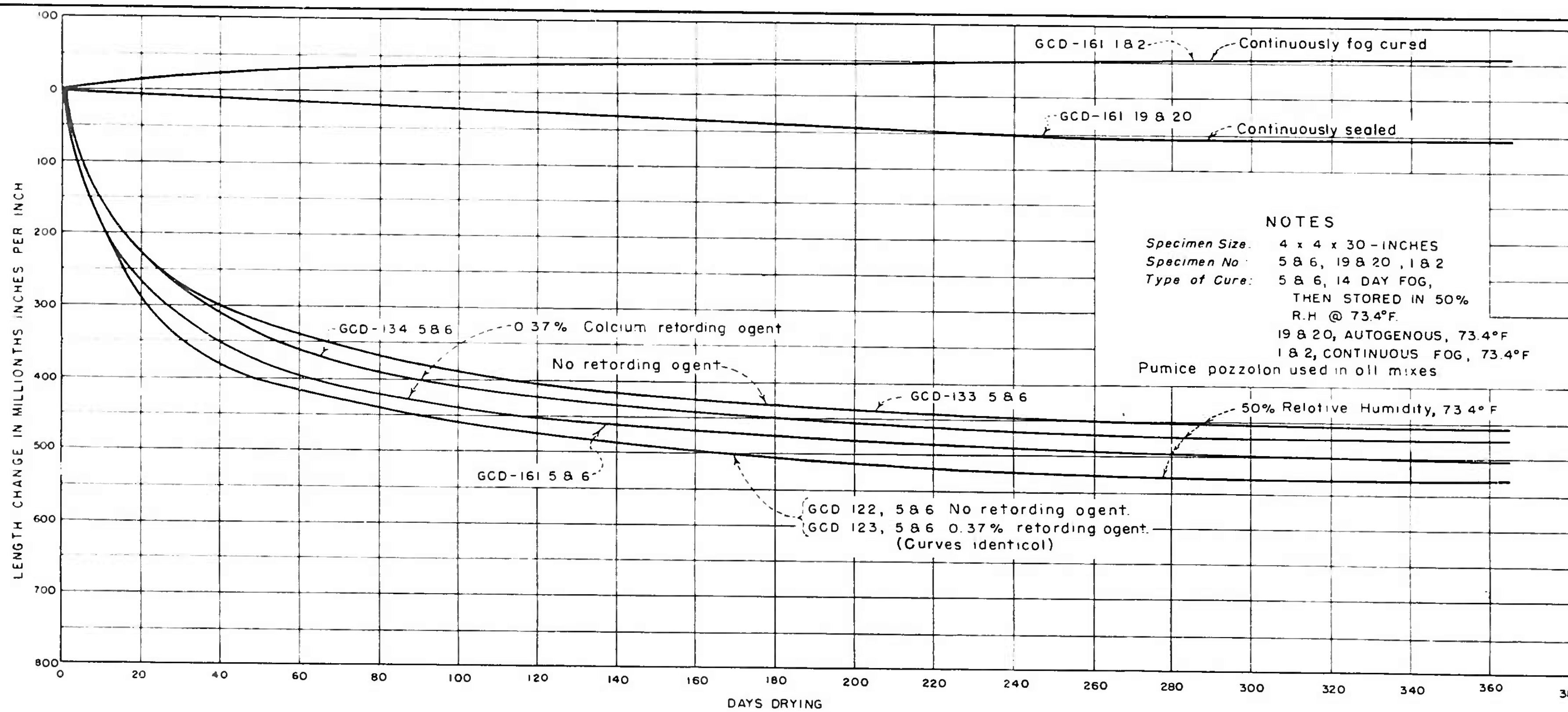
LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

FIGURE 7



DRYING SHRINKAGE OF MASS CONCRETE CONTAINING A RETARDING AGENT CURED UNDER DIFFERENT CONDITIONS
LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

FIGURE 8



LENGTH CHANGE OF MASS CONCRETE CURED UNDER DIFFERENT CONDITIONS

LENGTH CHANGE INVESTIGATION - GLEN CANYON DAM

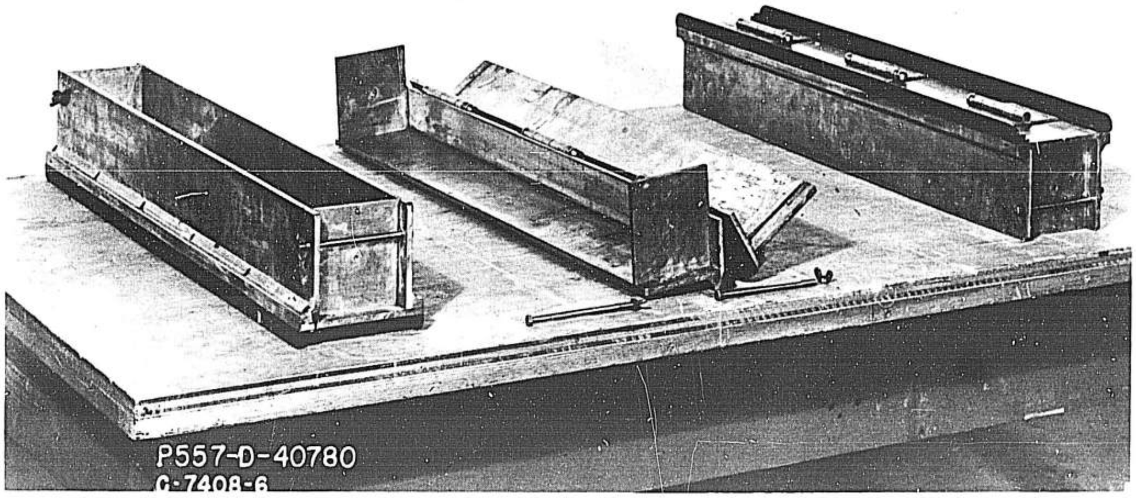


Figure 9 Steel molds used in the fabrication of 4 by 4 by 30 inch concrete test specimens.

Length Change Investigation-Glen Canyon Dam

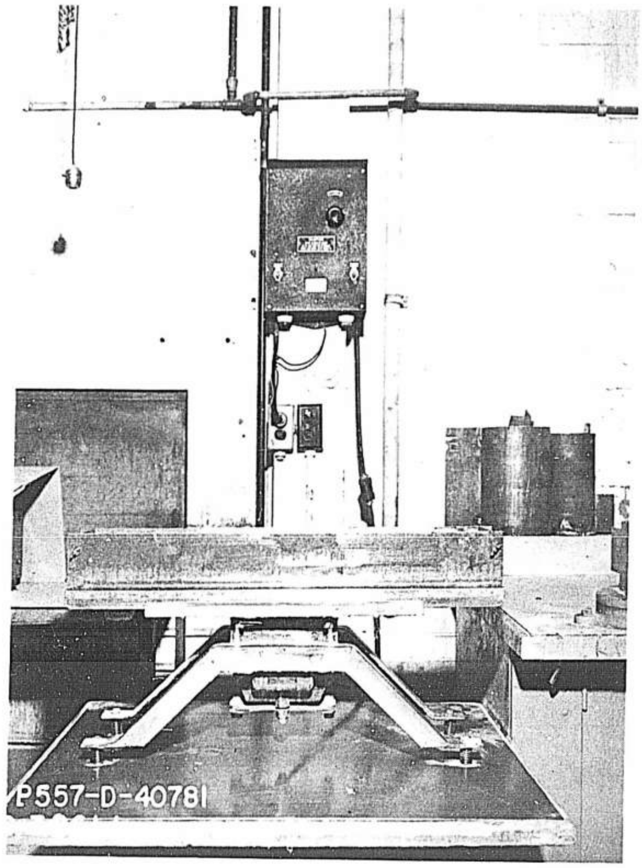


Figure 10 Vibrating table used to consolidate fresh concrete in the preparation of test specimens.

Length Change Investigation--Glen Canyon Dam

Figure 11 Horizontal Comparator for measuring length change of 4 by 4 by 30 inch concrete specimens.

Length Change Investigation--Glen Canyon Dam

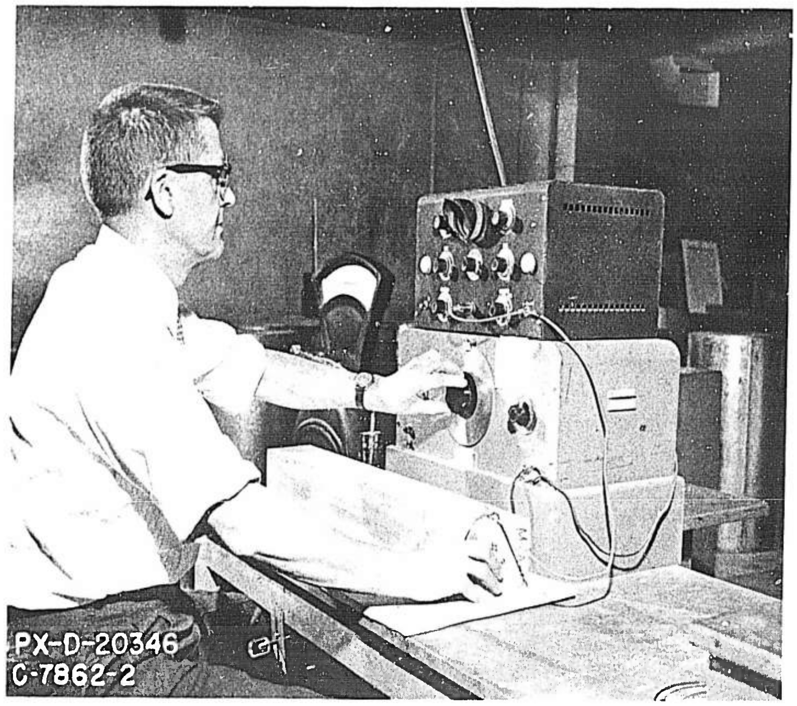


Figure 12 Electronic equipment for determining Young's Dynamic modulus of elasticity.

Length Change Investigation--Glen Canyon Dam

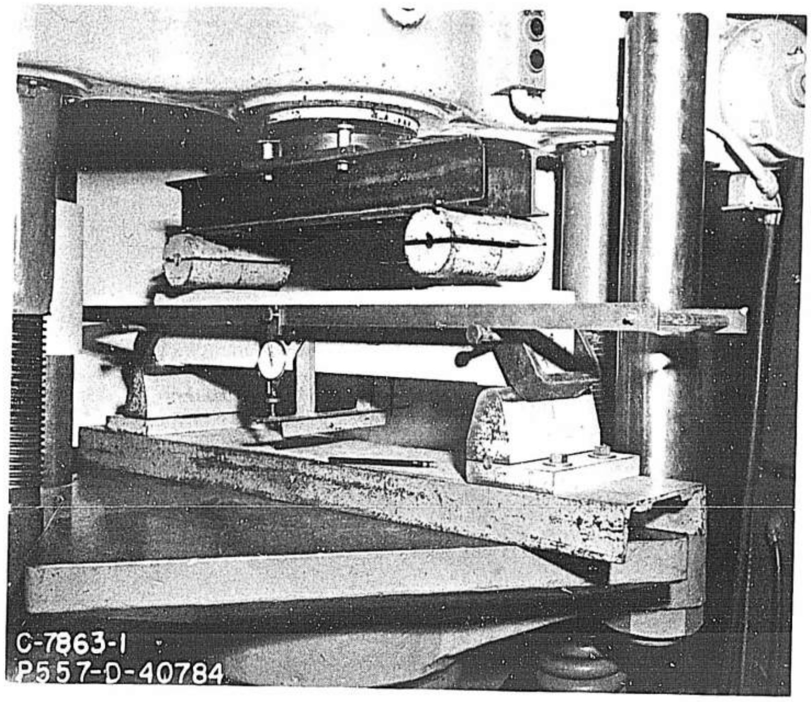


Figure 13 Frame and loading head used in flexure and modulus of rupture tests.

Length Change Investigation--Glen Canyon Dam